Arctic Terrestrial Environmental Research Programs of the Office of Energy Research, Department of Energy:

Evaluation and Recommendations

Appendix B:

Components of an Arctic Terrestrial Environmental Research Program. Report of a Workshop Held in Boulder, Colorado, 21-23 November 1982

Committee to Evaluate DOE's Arctic Terrestrial
Environmental Research Programs

Polar Research Board

Commission on Physical Sciences, Mathematics, and
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Report to the
Committee to Evaluate DOE's Arctic Terrestrial
Environmental Research Programs
Polar Research Board
Commission on Physical Sciences, Mathematics, and
Resources

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This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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Appendix B

Components of an Arctic Terrestrial Environmental Research Program

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Foreword

To receive advice on its Arctic research programs and how they can interact with and complement those of other agencies, the Department of Energy (DOE) asked the Polar Research Board of the National Research Council to assist it in formulating an Arctic terrestrial environmental research program. As a result, the Committee to Evaluate DOE's Arctic Terrestrial Environmental Research Programs was formed and held two meetings and a workshop. The Committee issued in early 1982 a two-volume report, Arctic Terrestrial Environmental Research Programs of the Office of Energy Research, Department of Energy: Evaluation and Recommendations and Appendix A: Terrestrial Environmental Research in Alaska During 1980-1981. The report includes recommendations for a coherent and integrated program of Arctic terrestrial environmental research consistent with DOE interests that might be used by the DOE Ecological Research Division in developing long-range research objectives and plans for their implementation.

The DOE subsequently requested that the Committee follow up its initial recommendations by identifying the specific components of an Arctic terrestrial environmental research program. The resulting plan, which is the subject of this appendix, elaborates on the Committee's earlier recommendations.

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Components of an Arctic Terrestrial Environmental Research Program

PURPOSE AND BACKGROUND

The U.S. Arctic contains proven and unproven reserves of oil and natural gas that represent up to 40 percent of the total amounts of undiscovered recoverable oil and gas resources remaining within the jurisdiction of the United States. As much as 50 percent of remaining U.S. oil resources may be in the U.S. Arctic (U.S. Arctic Coal and Gas, National Petroleum Council, Washington, D.C., 1981). Alaska's coal resources, underlying about 12 percent of the land, are large, perhaps equal to those of the rest of the United States. The area is also the last large reserve of relatively undisturbed wild lands in the United States. The needs both for energy and for wilderness values require that the development of energy technologies take into account the unique features of the environment. To take advantage of the large energy resources of Alaska, specific technologies related to surface mining, pipeline construction and road, railroad, and airfield construction will be developed by industry.

In addition to the specific physical features of the environment that energy technologies must overcome, Alaska is unique because of its wilderness and because the human populations of the Arctic maintain ties with traditions based on use of the living resources of the area. Almost none of the infrastructures of economically developed areas exists there, and when energy development occurs on a large scale, communities, roads, refineries, water and waste facilities, and the like must also be developed. Much, if not most, of the impact is likely to result from development of this kind rather than from the direct application of specific technologies. For these reasons, in its 1982 report, Arctic Terrestrial Environmental Research Programs of the Office of Energy Research, Department of Energy: Evaluation and Recommendations, the Committee to Evaluate DOE's Arctic Terrestrial Environmental Research Programs recommended that the U.S. Department of Energy (DOE) exercise its environmental responsibilities broadly by identifying where energy developments are likely to occur, the kinds of impacts that can be expected, and the measures that can be used to mitigate them by supporting the required scientific research.

The Committee also recommended that DOE continue to fulfill its mission in the Arctic by supporting a program of research that will:

1. Focus on the problems of environmental quality resulting from energy technologies and programs;
2. Use the techniques of experimental manipulation to predict the impacts of energy development on environmental integrity;
3. Bring knowledge already developed in environmental research to bear on the problem of maintenance of environmental integrity;
4. Produce scientific results that are applicable to many types of sites and landscapes; and
5. Gain an understanding of short-term and long-term environmental effects of disturbances so that better management decisions can be made about alternative development procedures, protection, and restoration.

The report also recommended that a large part of the future research supported by DOE concentrate on long-term intensive studies of the environmental effects of energy-related developments in the Arctic region. These studies would be centered initially in one landscape, either in the tundra or in the taiga zone of Alaska. A number of research projects, perhaps 8-10 at a time, would work within this landscape unit; research sites would include a stream and several vegetation types, such as tussock and shrub tundra, plus riparian vegetation or tundra and boreal forest.

These studies would emphasize the effects of disturbance on species and on ecosystem processes. To achieve these objectives, a series of manipulations of the environment would be incorporated into the landscape study. As examples, vegetation and gravel would be removed from a section of a stream valley and the impact and recovery monitored, an ice road would be constructed, or a small area would be artificially acidified. In each of these studies, the undisturbed system or process would serve as a control. Each manipulated area would be studied by several projects. An important process that is affected by these impacts, such as nitrogen fixation, might constitute a single project and would be measured at the site before manipulations begin. After a period of initial studies, which would include determinations of rates and of controls, manipulations would take place and the nitrogen-fixation project would begin to investigate their effects over a period of several years. Simultaneously, other projects would make other measurements in the same plots or treated areas. Finally, recovery from the manipulations would be investigated at a lower intensity for several years.

The landscape project would be coordinated and integrated by a single scientist (project coordinator) and an advisory committee. The individual research projects would be integrated by their investigation of a single landscape, their common need for information about all parts of the system, and ecosystem-level measurements (e.g., total energy available from photosynthesis) that would be needed by all projects. Additional information on organization appears in Chapter 5 of the Committee's 1982 report.

The site-intensive approach does have two major disadvantages. First, no single site is likely to include the range of environmental conditions in which energy development will occur. Second, the results of the research conducted at the primary site cannot be generalized to other kinds of areas without some independent test of their validity. Thus the Committee recommended that secondary (extensive) sites be established to solve these problems. The primary site would be selected on the basis of its similarity to those geographic areas in which energy development is most likely to occur and about which information is urgently required. Emphasis could be changed to secondary sites if indicated by shifts taking place in the locations in which energy development is occurring.

The Committee recognized that it is in the interest of Arctic science that DOE continue to support certain independent projects related to the impact of energy development in Arctic Alaska. Some of these projects are not appropriate to the concept of the integrated research design described above. These projects should involve immediate environmental problems such as monitoring wildlife populations, mapping vegetation, measuring ambient levels of suspected pollutants, and the like.

To develop the Committee's recommendations in greater detail, a workshop involving Arctic scientists representing the major disciplines involved in terrestrial environmental research was held at the University of Colorado in November 1982 (the participants are listed on p. v).

Participants in the workshop were chosen by the Committee to represent those specific areas of expertise that are most appropriate to integrated research at the ecosystem level. Each was sent a copy of the Committee's report and a letter explaining the purposes of the workshop. Each workshop participant was also asked to complete in advance an energy development impact matrix for the specialty he or she represents. The matrix was designed in such a way as to describe for each energy development impact the systems that are most sensitive to it, the most sensitive components of these systems, and the short- and long-term processes affected.

After an initial discussion of the task and methodology of the workshop, participants reviewed the Committee's report and recommendations. Consensus was reached quickly on the research areas that should have priority in a long-term research program. The participants then turned their attention to designing a specific research plan that would address the agreed-on priorites, emphasizing in particular critical research needs. The workshop concluded with a discussion of sites at which the integrated research could best be carried out. A high degree of consensus prevailed at the workshop and in the conclusions reached. This report presents the main ideas and conclusions generated at the workshop.

IMPACTS ON THE ENVIRONMENT

The Arctic terrestrial environment is vulnerable to the impacts of disturbance, but, as has been demonstrated in recent large-scale projects such as the Trans-Alaska Oil Pipeline System, protective and mitigative actions can prevent or remedy many of the impacts. These advances in environmental protection have been impressive, and they have been made possible largely by the knowledge that has accumulated from many years of Arctic research.

As development continues in the Arctic, the degree and kinds of environmental impacts will intensify. Some will be the result of specific energy technologies, but most of them will be associated with the development of roads, airfields, communities, refineries, water and waste facilities, and the like. In general, these developments will be accompanied by (1) the destabilization of slopes; (2) the disruption, removal, or burial of the surface organic mat; (3) changes in drainage; (4) chemical changes; and (5) toxic effects. Research is urgently needed on these kinds of impacts. A research plan that the DOE might support should have a close relationship to these potential effects. This information will help the DOE to fulfill its mission and should be equally useful to industry in guiding efforts to develop the nation's energy resources in a manner consistent with the goal of preserving environmental quality.

APPROACH TO RESEARCH

The research accomplished under this program should be integrated--that is, the separate research studies should be planned and conducted with as much interaction and knowledge of other studies as possible, using the same experimental sites, comparable methodology when appropriate, and frequent exchange of information. Experience with other multidisciplinary programs of research on ecosystems has convinced the workshop participants that integrated research can be accomplished most successfully if integrated planning is done in advance of the research. For this reason, it is recommended that a project coordinator (called Project Director) in the Committee's report (pp. 5, 32) be responsible for the integration of the research program. The project coordinator should be a person with substantial experience in Arctic research and in integrated ecosystems research. This person would be expected to direct a scientific research component in addition to being responsible for integrating research efforts. Funds for logistic support and for integration and synthesis should be under the direction of the project coordinator, who should also be charged with the responsibility of coordinating the presentation of the results of the research in a form that is most immediately useful to native groups, state and federal agencies, and industry. Thus, although the specific recommendations that follow are described separately for emphasis and clarity, a research program that is integrated from the earliest planning stage onward is essential if the program is to be productive and the results rapidly applied.

The research program that is proposed has a number of advantages:

1. The results could be generalized to other Arctic sites, especially if independent tests of their validity are conducted. This broader application is possible because basic processes of the natural environment are studied. Thus an understanding would be gained of the expected results of an impact as well as the causal mechanisms. If the same species or processes are present at a different site, then the impact should be predictable and perhaps experimentally validated.

2. The whole landscape would be examined for the selected impacts. A number of scientists would examine several effects on various processes and species; this approach would provide intensive study of a type of impact that would not be possible if a single scientist examined a specific impact. In addition, by focusing on a single landscape, unexpected effects at interfaces of landscape units could be discovered.

3. The research could produce information on long-term effects and recovery. Particularly in the terrestrial system, effects of disturbances may take years to become obvious. Recovery from impacts could be assessed to understand the system and to predict (a) whether an impact will be short-term or permanent, (b) whether it will be continued by the affected system, or (c) whether there will be "downstream" effects that will affect other systems.

4. Basic scientific information could be used from the proposed study and from the scientific literature to solve applied problems. The emphasis would be on how species and ecosystem processes respond to environmental impacts. Information is especially needed on Arctic environments.

5. The concentration of research activities at a single site would be cost-effective for northern research--Arctic and sub-Arctic research is costly because of logistics, and those costs could be greatly reduced by having projects at 1 or 2 sites instead of 8 or 10 widely scattered sites.

6. This approach would provide a framework for

making judgments about priorities for research and performance of research already under way. Once the site and impacts to be tested are chosen, the research priorities could be assigned according to how well the projects will answer questions about the ways in which the landscape and the ecological processes are being affected.

7. The predictions would be made on the basis of knowledge of species, processes, and controlled experiments using the expected impacts and would permit better planning to maintain environmental integrity.

8. The research program would enhance the training of Arctic scientists who, by virtue of the experience gained in tundra and taiga environments, will be able to predict the impact of various disturbances of the environment.

RESEARCH PRIORITIES

General Priorities

In discussing research priorities for Arctic terrestrial environmental research, the workshop participants identified several consistent themes. First, the impacts of most disturbances can be translated into how they change soil moisture and soil temperature regimes and how these, in turn, produce a variety of ecological and environmental effects. It was recognized that chemicals and toxic substances also have direct effects on ecosystems. Second, soil factors in general are of the utmost importance in Arctic ecosystems, because almost all biological activity is concentrated in a relatively thin active layer above the permafrost. Third, the long-term effects of disturbance need to be understood in order to assign priority to research on environmental and ecological impacts.

The workshop participants agreed that DOE's Arctic Terrestrial Environmental Research Program should have an integrating theme: "Impacts of and Recovery from Disturbance--The Controlling Role of Changing Water, Chemical, and Thermal Regimes."

The general objectives of studies proposed under the integrating theme are to determine: (1) the impact of a disturbance on the water and temperature regimes in Arctic soils, (2) the impact of chemical and toxic substances on Arctic ecosystems, and (3) the length of time and the mechanisms by which these changes are overcome through ecological succession and seasonal response.

The soil system in the Arctic is unique in several respects. Permafrost underlies it nearly everywhere. Most soils are acidic and highly organic, and little is known of biological processes in these soils. Disturbance of the organic mat or of the active layer, however minor, alters the characteristics of the soil. At some point the complex of soil properties that maintains the existence of permafrost is violated, and there is a tendency for the soil system to break down more or less irreversibly, primarily due to the cascade of environmental effects that arises when the underlying permafrost thaws. It is doubtful in these extreme cases of disturbance that complete recovery ever occurs. To a significant extent, artificial disturbances mimic natural ones, so it is important to understand the homeostatic mechanisms that promote natural equilibrium.

In situations in which the soil equilibrium is not upset, disturbed systems tend, in time, to become covered once again by vegetation and to rebuild themselves. In general, severely disturbed systems require more time for recovery than lightly disturbed ones, but the relationship between the degree of disturbance and the time needed for recovery is probably not linear.

Specific Recommendations

Research on riparian ecosystems should have the highest priority in an Arctic environmental research program. Riparian ecosystems are characterized by the presence and under the influence of standing or running fresh water, such as streams, ponds, or small lakes. Although they account for a relatively small proportion of the landscape, riparian systems are unusually important among Arctic ecosystems. The presence of surface running water or water in streams produces better soil aeration and more favorable moisture conditions for plant growth. Taller and denser growths of shrubs occur in these situations, which, in turn, encourage relatively heavy use by herbivores in both summer and winter. In terms of their practical importance, freshwater streams are a main source of food (fish) and water to human populations in the Arctic. They are used as a source of sand and gravel for construction purposes in the North, and in any future developments they are almost certain to be among the most heavily used of all Arctic ecosystems. Yet, among Arctic ecosystems, they are probably the least studied and most poorly understood.

Research concerned with the impact of developments on slopes should receive second-highest priority. Due to the presence of permafrost, soil tends to flow on slopes of even low angles (>5°). Only level ground is free of the slope effects of disturbance. Slope angle, the degree of water saturation, the presence or absence of vegetation, and other factors determine the widespread types of disturbance that may occur on gentle to moderate slopes, which characterize Alaska's North Slope.

A potentially large number of human impacts on the environment constitute a third priority. Three kinds of construction activity are of concern: (1) The construction of features such as roads and airfields, utility corridors, pipelines, and other transportation and communication structures changes drainage patterns and thus affects soil properties. (2) The construction of fixed-point sources of air pollution, such as refineries and utility plants in addition to an increase in vehicle traffic, will produce increased levels of air pollution. (3) Construction in general, for all construction in the terrestrial Arctic in one way or another affects vegetation by burying, removal or disruption of the vegetation mat.

RESEARCH PLAN

We have outlined a sequence of research projects that should be carried out during the first several years of the integrated research program. The plan presented assumes that most of the research will be conducted on a single intensive site and that a number of investigators will be engaged in simultaneous investigations, which will be coordinated by a Project Coordinator. Some research will be done at secondary sites as dictated by the needs of the overall project. One of the major functions of the Coordinator will be to attempt to achieve a high degree of integration among the several research projects taking place at the site.

Descriptive Background Studies

Concentration of the research at a single intensive site will require that general baseline studies be conducted as background to the experimental manipulative studies that will follow. The following are proposed as the kinds of baseline studies to be conducted:

a. Preparation of a topographic base map at a scale of about 1:10,000, with a contour interval of about 2 m. A locational grid for clearing and registering all study plots should be established.

b. Development of checklists of major components of the biota--vascular plants, bryophytes, and lichens; major vertebrate and invertebrate groups.

c. Establishment of one or more standard climatic stations.

d. Assessment of the climatic history of the area using the data from: dendroclimatology ($10-10^2$ yr); pollen analysis and climatic transfer functions (10^1-10^3 yr); and changes in geomorphic processes and the scale of response (10^2 -10^4 yr).

e. Production of specialized maps, such as (1) slope disturbance maps, which will contain information on insolation and geomorphic features indicative of slope movements, such as solifluction lobes, ice wedge polygons, and surficial geology; (2) vegetation maps; and (3) predictive maps to estimate the ice content of frozen ground, the depth of the active layer, soil temperatures, rates of soil flow, and soil types.

f. Evaluation of natural disturbances, including (1) solifluction, tundra earthflows, frost heaving, and thermokarsting; (2) drainage blockages; (3) air pollution; (4) snow accumulation; (5) stream erosion; (6) aufeis; and (7) interactions.

Experimental and Manipulative Studies

Riparian Ecosystems: The Impact of and Recovery From Disturbances

From work in other regions, we can predict in some detail the kinds of impacts that development would have on the riparian ecosystem. Most obvious and damaging are the direct effects of construction. Changes in stream morphology, drainage, and water velocity, if severe enough, can locally destroy the natural ecosystem. Downstream from such disturbances the status of sediments and nutrients can be changed for long distances. Toxins may be introduced or, if already present, increased. Streamside and aquatic vegetation may be damaged and destroyed by any or all of these physical changes; and destruction of vegetation has a cascade of effects on other living organisms.

Each of these system changes has specific implications. For example, changes in sediment status will affect insect and fish populations, algal productivity, turbidity of streams and lakes, and stream morphology. Using the example of nutrients, we suggest the following research protocol:

Nutrients

a. Manipulation

(1) Measure initial conditions
(2) Establish upstream controls
(3) Add nutrients at n levels

b. Change and Recovery

(1) Fate of nutrients at distribution
(2) Hydrology and nutrient budgets
(3) Primary production (algal populations)
(4) Animal populations (fish, insects)

Direct fieldwork of this type should be complemented by laboratory experiments in which conditions can be controlled more carefully, often by simulations using modeling techniques to extend the predictive capability of the empirical data. The example of nutrients is intended to give direction to but not restrict the imagination of scientists who propose research for this program. The sequence of thought is the common approach that ties these sometimes disparate studies together: (1) from anticipating human impact; (2) understanding which important system changes flow from these impacts; (3) predicting the implications of these changes in system functions; (4) designing experiments that lead to a better understanding of how the system functions under natural and induced conditions; (5) to determining how and when the system recovers from disturbance. Similar research protocols are appropriate for the many kinds of experimental manipulation that mimic and model development activities.

For this work to be of the greatest value in predicting and helping mitigate the effects of impacts like those described, the status of populations of control and experimental organisms should be monitored over a period of several years or longer.

Impacts of and Recovery From Disturbances on Slopes

Three main types of natural disturbances are widespread on slopes of gentle to moderate gradient, which are characteristic of much of Alaska's North Slope:

1. Slow rates of flow, up to 1-2 cm/yr (solifluction and creep);
2. More rapid rates of flow, 1-5 m/yr or more (tundra earthflows; slope failure-instantaneous flows); and
3. Erosion by running water (sheetwaste, gully incision).

All three types of disturbance can be greatly accelerated by damage to vegetation, thaw of the permafrost, and other effects of human activities.

The initial stages of this project should be included in the descriptive baseline studies of the intensive site, described earlier. The descriptive and predictive mapping should be followed by attempts to evaluate natural slope processes.

Large-scale effects, too large to be simulated and accommodated on the intensive study site, should be studied at extended sites; such studies should take advantage of developments that are occurring in Arctic Alaska.

The expected large-scale effects that should be monitored throughout the project should include: (1) increased rate of slope movement; (2) increased frequency of movements; (3) increased flux of sediments and nutrients to streams; and (4) burial of soil and vegetation.

The research protocol described above (the nutrients example) should be followed in the intensive site experimental and manipulative work, and, to the extent possible, the slope impact studies should be combined with other projects to minimize overall damage to the intensive site and to minimize costs.

Impacts on Recovery from Changes in Drainage, Air Pollution, and Vegetation Removal

In addition to the well-defined impacts of riparian systems and of slopes, several other kinds of impacts can be identified. In some respects they overlap the first two categories, but the workshop participants identified situations in which development leads to impacts that may not be found in association with streams or slopes. They include but are not limited to the impact of air pollution on tundra ecosystems; changes in drainage patterns due to the construction of roads, pipelines, airfields, and other transportation and communication structures; and the effects on tundra ecosystems of the removal, burying, or other disruption of the vegetation. All of these kinds of development have an immediate or potential effect on soil temperatures and moisture levels and thus influence the structure and functioning of ecosystems.

Air Pollution Investigations of the impact of air pollution on the tundra are less easily confined to the intensive site than the other studies listed. It is clear that air pollution is a problem in the Arctic, and it is reasonable to assume that development will exacerbate it. It is also known from the Arctic Air Sampling Network data that air pollution generated elsewhere is now influencing the Arctic. Certain categories of important Arctic plants, particularly lichens, are highly susceptible to air pollution.

It is expected that a direct relationship will exist between point sources of air pollutants and their concentrations. In general, concentrations of air pollutant fallout should be inversely proportional to distance from the point source, and concentrations should be higher downwind of the source. It is suggested that research in this area begin with a geographic survey of the status of air pollution with respect to point sources. Specific effects of pollution should be investigated and mapped. Finally, experimental manipulation of pollutant concentrations should be attempted on ecosystems of different types.

Drainage Changes Although the major flow of surface water in the Arctic occurs, as elsewhere, in incised drainages, the presence of permafrost results in a substantial lateral movement of water on any slope. The construction of elevated structures, such as roads, runways, pipelines, and other communication and transportation structures, effectively blocks the flow of this surface and subsurface water, especially where permafrost has formed in the structure. The result is the formation of impoundments, which, in turn, produce often radical changes in affected ecosystems. Examples of impoundments are seen along the Dalton Highway, which parallels the Tran-Alaska Oil Pipeline, and in a number of places in the Prudhoe Bay area. On a regional basis the sometimes subtle changes produced by drainage pattern modifications may be the largest category of changes produced by development.

Because of the existence of a large number of impoundments whose time of origin is known in many instances, this research should begin with a documentation of existing impoundments and their effects at sites in Arctic Alaska. At the intensive site, impoundments should be constructed, and detailed analyses of the progressive changes in physical and biological characteristics measured. Soil temperature, moisture, and chemical characteristics will be affected and in turn will influence the kind, amount, and quality of plant growth, consumption of plants by animals, and decomposition.

Vegetation Removal All construction in the terrestrial parts of the Arctic affects vegetation by either burying, removal, or disruption of the organic mat. Although considerable research has been done in attempts to restore vegetation on denuded sites in the Arctic, particularly in conjunction with the construction of the Trans-Alaska Oil Pipeline System, much of the basic research on the subject remains to be done. Long-term research at the intensive site is ideally suited to address questions related to restoration of plant cover.

After establishing existing conditions of vegetation cover, plants should be removed from experimental sites, using different partial or complete removal strategies. Changes in soil temperature, moisture, nutrients, and decomposition should be followed on control plots and should be manipulated in experimental plots. Different reclamation strategies should be attempted and should include detailed observations on the dynamics of plant populations. Herbivory by insects, birds, and mammals should be measured. It is expected that laboratory and greenhouse experiments would be conducted in conjunction with these field studies.

As an adjunct to the experimental studies, existing disturbance and recovery of vegetation on disturbed areas should be studied at extensive sites.

The research protocol described under work in riparian systems should be followed in the intensive site experimental and manipulative work, and, to the extent possible these studies should be combined with other projects to minimize overall damage to the intensive site and to minimize costs.

RESEARCH SITES

We recommend that the research described in the preceding sections be conducted in Arctic Alaska as opposed to the boreal forest portion of the state. This recommendation is based on the belief that the most likely area for energy resource development, and that from which information is most urgently needed until the year 2000, is the area north of the Brooks Range in Alaska. We do recognize, however, that water power projects may take place in other parts of Alaska in the near future and that coal mining will be an ongoing industry in the Alaskan interior for the foreseeable future.

As we had expected, once a research plan was outlined, the choice of research sites was considerably narrowed. The workshop participants identified the following as important criteria for research site selection:

(1) Ease of access
(2) Up to 200 m of relief (for studying slope effects)
(3) A diversity of riparian sites
(4) A variety of types of slope instability
(5) Area beyond the limit of the last glaciation characteristic of most of the North Slope region)
(6) Opportunity to have a control area nearby with similar characteristics
(7) Existing knowledge of site available
(8) Large-scale human disturbance nearby
(9) Existence of ongoing research projects nearby
(10) Application of results to other agencies' needs possible
(11) Native heritage concerns (such as caribou hunting)
(12) Logistic costs reasonable
(13) Security of site ensured (until the year 2000)

Several possible sites identified in the Committee's earlier report (Cape Thompson, Barrow, Caribou-Poker Creeks) were eliminated from further consideration because they did not meet one or more of the criteria. Final consideration centered around Toolik Lake, Prudhoe Bay, Kuparuk, Umiat, and a Haul Road site beyond that of the last glaciation, such as Happy Valley. A matrix was prepared (Table 1), which ranks each site according to the criteria identified above.

After detailed consultation with the workshop participants, we selected two sites, both of which satisfy most of the selection criteria, but each of which has one or more potential problems. The Toolik Lake-Happy Valley area is the first; its one major liability is that Toolik Lake lies within the area of

TABLE 1 Criteria for Research Site Selection

Criterion	Toolik	Prudhoe	Kuparuk	Umiat	Dalton Highway Beyond Last Glaciation
Access	1	1	1	2	1
Relief 50-200 m	1	3	2	1	1
Diversity	1	2	2	1	1
Beyond last glaciation	2	1	1	1	1
Nearby control	1	2	1	1	1
Nearby human disturbance	1	1	1	1	1
Background data	1	1	2	2	2
Ongoing research nearby	1	1	2	1	2
Application of results to other agencies' needs	2	1	1	2	2
Native heritage concerns	1	1	1	1	1
Logistic cost	1	2	2	3	2
Security of site until the year 2000	1	3	2 or 3	1 or 2	1

1 = most favorable; 3 = least favorable.

the last glaciation. Happy Valley does not, so a combination of the two (they are within 50 km of each other on the Haul Road) would eliminate the problem. The problem of site ownership will have to be satisfied, because these long-term studies must be conducted on a site that can be guaranteed for at least 15 years. The second recommended site, Kuparuk, has two major problems--site security and a lack of relief; therefore, it ranks somewhat lower than Toolik Lake-Happy Valley.

SCHEDULE

We developed the following recommended timetable for the research program:

Year 1	Selection of the project coordinator Survey work and mapping Planning for the site manipulations (it is suggested that consulting with engineers would be appropriate) Consideration of routes of travel to and through the intensive site
Year 1-5	Continuous monitoring of populations
Year 2	Major manipulations begin
Year 2-5	Experimental work

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